Volume 109
Number 1
Spring 2023

# Journal of the WASHINGTON ACADEMY OF SCIENCES

## 125th Anniversary Celebration!



ISSN 0043-0439
Issued Quarterly at Washington DC

# Washington Academy of Sciences

## Founded in 1898




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# Journal of the WASHINGTON ACADEMY OF SCIENCES

## *The 125th Anniversary Issue*

WASHINGTON ACADEMY OF SCIENCES
1898



**ISSN 0043-0439**

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# EDITOR'S COMMENTS

This year the Academy celebrated its 125$^{th}$ Anniversary at the historic George Washington Masonic National Monument. The annual meeting and awards banquet brought together the brightest minds in our community to celebrate scientific achievement and to recognize the outstanding contributions of our members. The Academy presented awards for Distinguished Career in Science, Excellence in Research, and Teaching Awards to several deserving scientists, engineers and educators.

As part of the 125$^{th}$ anniversary celebration, Lynnette Madsen has given us a historical perspective by compiling a list of the presidents of the Academy since its founding in 1898. In addition to tables, images and references, she relates some of the stories that past and present members were willing to provide about our history. Lynnette's contribution brings a fresh perspective on the future.

In the climate science literature, there are many references to an experiment performed over a century ago which claimed to show that the greenhouse effect is primarily caused by blocking air convection. In spite of the fact that this experiment was criticized at the time and was never replicated, global warming skeptics continue to invoke the article when attempting to cast doubt on climate science today. The article by Paul Arveson reviews recent efforts, including his own, to replicate the experiment and concludes that the century-old experiment is incorrect.

Sadly, the day before the annual meeting, Vary T. Coates passed away. She was the editor of this Journal prior to Sethanne Howard and was a long-time Life Fellow and supporter of the Washington Academy of Sciences. Sethanne prepared a brief remembrance of Vary to close this issue.

Please send any news about yourselves as well as your comments on papers, suggestions for articles, and ideas for what you would like to see in the Journal to editor@washacadsci.org.

Kenneth Baclawski

## Journal of the Washington Academy of Sciences



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The *Journal of the Washington Academy of Sciences* has a Board of Discipline Editors representing many scientific and technical fields. The members of the Board of Discipline Editors are affiliated with a variety of scientific institutions in the Washington area and beyond — government agencies such as the National Institute of Standards and Technology (NIST); universities such as Georgetown; and professional associations such as the Institute of Electrical and Electronics Engineers (IEEE).

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|---|---|
| Spring – February 1 | Fall – August 1 |
| Summer – May 1 | Winter – November 1 |

2. Draft Manuscripts using a word processing program (such as MSWord), not PDF. We do not accept PDF manuscripts.
3. Papers should be 6,000 words or fewer. If there are seven or more graphics, reduce the number of words by 500 for each graphic.
4. Include an abstract of 150-200 words.
5. Use Times New Roman, font size 12.
6. Include two to three sentence bios of the authors.
7. Graphics must be easily resizable by the editor to fit the Journal's page size. Reference the graphic in the text.
8. Use endnotes or footnotes. The bibliography may be in a style considered standard for the discipline or professional field represented by the paper.
9. Submit papers as email attachments to the editor at editor@washacadsci.org.
10. Include the author's name, affiliation, and contact information - including postal address. Membership in an Academy-affiliated society may also be noted. It is not required.
11. Manuscripts are peer reviewed and become the property of the Washington Academy of Sciences.
12. There are no page charges.

## Washington Academy of Sciences
## Affiliated Institutions

| |
|---|
| National Institute for Standards & Technology (NIST) |
| Meadowlark Botanical Gardens |
| The John W. Kluge Center of the Library of Congress |
| Potomac Overlook Regional Park |
| Koshland Science Museum |
| American Registry of Pathology |
| Living Oceans Foundation |
| National Rural Electric Cooperative Association (NRECA) |

# $125^{th}$ Anniversary Gala and Awards Banquet

Our $125^{th}$ Anniversary Gala and Awards Banquet was held on May 12, 2023 in the Grand Masonic Hall in Alexandria, VA. The Academy presented awards for Distinguished Career in Science, Excellence in Research, and Teaching Awards to several deserving scientists, engineers and educators. A delicious catered dinner was served.

## Past President Speech

Dear Esteemed Members and Honored Guests,

It is my pleasure to welcome you to the $125^{th}$ anniversary celebration of the Washington Academy of Sciences. This annual meeting and awards banquet is a special occasion that brings together the brightest minds in our community to celebrate scientific achievement and to recognize the outstanding contributions of our members. As my term as President of this esteemed academy comes to a close, I want to express my deepest gratitude for the opportunity to serve and lead such an incredible community of scholars, researchers, and educators. It has been an honor to work alongside such a distinguished group of colleagues, and together we have made critical decisions, provided strategic guidance, and worked to advance the goals and objectives of the Academy. Our collective expertise, vision, and commitment have been instrumental in driving the Academy's success. I am confident that the Academy will continue to thrive under the leadership of the incoming President, Mahesh Mani. As we look to the future, there is still much work to be done. I encourage you to remain committed to the Academy's mission, to continue seeking new opportunities for growth and impact, and to always act with integrity and excellence. We must continue to support and empower the next generation of scientists, to foster a love of discovery and a commitment to excellence. As I transition to immediate past president, I am confident that the Washington Academy of Sciences will continue to thrive and make an enduring impact, particularly in the Washington DC area. Thank you for your dedication and your unwavering commitment to advancing the cause of science.

Sincerely,

Lynnette Madsen

## 2023 Award Recipients

Dr. Ramalingam Chellappa: Distinguished Career Award in Engineering Sciences

Dr. Mohammad Taghi Hajiaghayi: Distinguished Career Award in Applied Mathematics

Dr. Jeffrey Voas: Distinguished Career Award in Computer Science

Dr. Paul Cotae: Excellence in Research Award in Engineering Sciences

Dr. Andrea Centrone: Excellence in Research Award in Physical Science

Dr. David James Gundlach: Excellence in Research Award in Electrical Engineering

Dr. Paul Chan: Leadership Award in Climate Science

Dr. Dana L. Wolff-Hughes: Leadership Award in Behavioral Sciences

Dr. Craig Ian Schlenoff: Leadership Award in Manufacturing Engineering

Dr. Anqing Zhang: Early Career Award in Healthcare

Dr. Amy Mensch: Young Investigator Award in Engineering Sciences

Mr. Steve Lavalle: Krupsaw Non-Traditional Teaching Award

Ms. Archishma Marrapu: Student Achievement Award

## Distinguished Career Award in Engineering Sciences
## Ramalingam Chellappa

Ramalingam Chellappa receives the Distinguished Career Award in Engineering from Dinesh Manocha.

## Distinguished Career Award in Applied Mathematics
## Mohammad Taghi Hajiaghayi

Mohammad Taghi Hajiaghayi receives the Distinguished Career Award in Applied Mathematics from Ming Lin.

# Distinguished Career Award in Computer Science
# Jeffrey Voas

Jeffrey M. Voas receives the Distinguished Career Award in Computer Science from Ram Sriram.

# Excellence in Research Award in Engineering Sciences
# Paul Cotae

Paul Cotae receives the Excellence in Research Award in Engineering Sciences from Devdas Shetty.

## Excellence in Research Award in Physical Science
## Andrea Centrone

Andrea Centrone receives the Excellence in Research Award in Physical Science from David Gundlach.

## Excellence in Research Award in Electrical Engineering
## David James Gundlach

David Gundlach receives the Excellence in Research Award in Electrical Engineering from Gerald Fraser.

## Leadership Award in Climate Science
## Paul Chan

Paul Chan receives the Leadership Award in Climate Science from Paul Arveson.

## Leadership Award in Behavioral Sciences
## Dana L. Wolff-Hughes

Dana L. Wolff-Hughes receives the Leadership Award in Behavioral Sciences from Ram Sriram.

## Leadership Award in Manufacturing Engineering
## Craig Ian Schlenoff

Craig Ian Schlenoff receives the Leadership Award in Manufacturing Engineering from Kevin Jurrens.

## Early Career Award in Healthcare
## Anqing Zhang

Anqing Zhang receives the Early Career Award in Healthcare from Tien Wong.

# Young Investigator Award in Engineering Sciences
# Amy Mensch

Amy Mensch received the award for Young Investigator in Engineering Sciences.

## Krupsaw Non-Traditional Teaching Award
## Steve Lavalle

Steve LaValle received the Krupsaw Non-Traditional Teaching Award from Vijay Kowtha and the Principal of Chesapeake Math & IT Academy.

# Student Achievement Award
# Archishma Marrapu

Archishma Marrapu receives the Student Achievement Award from Judy Staveley.

Front row: A. Marrapu, J. Voas, J. Anderson,
R. Chellappa, A. Mensch, M. Orcutt.
Back row: M. Taghi, D. Gundlach, A. Centron,
L. Madsen, D. Wolff-Hughes, C. Schlenoff.
Not shown here: P. Chan, P. Cotae, S. LaValle, A. Zhang.

# Presidents of the Washington Academy of Sciences
## A Historical Perspective for the Quasquicentennial

Lynnette D. Madsen
President, Washington Academy of Sciences

### Abstract

A compilation of the presidents of the Washington Academy of Sciences (WAS) is presented for the quasquicentennial. More details are provided for a few presidents. Pointers to articles chronicling key events, presidential addresses, annual awardees and information about the Academy in the past quarter-century are included.

### Background

**FOR THE 125$^{th}$ ANNIVERSARY** (quasquicentennial) of the Washington Academy of Sciences (WAS) in 2023, I compiled a history of the past WAS presidents. As I put this article together, I am reminded of the years that I worked at The National Air and Space Museum of the Smithsonian Institution in Washington, D.C. in the Space History department as a Research Associate. While one can comb through a massive amount of paper and scanned copies for facts and data, it is usually the stories from the people who worked and lived in that era that make everything come to life. In terms of space history, I learned the most in the shortest period from astronaut Dr. Bonnie Dunbar. Additionally, I spent many enjoyable hours learning about and exploring our past with Dr. Valerie Neal, a career space historian. What I gleaned from this experience is that being correct is important, but I also came to appreciate the value in pulling together history to bring a fresh perspective on the future. In this vein, I have attempted to capture some of WAS' presidential history through tables, images, and references - and the stories that past and present members were willing to provide.

### The Early Years of the Washington Academy of Sciences (WAS)

The first president of the Academy was James (John) R. Eastman of the U.S. Naval Observatory (Figure 1).[1] The second president, Charles D. Walcott (Figure 2) who held the position for over a decade, was an American paleontologist, a former director of the United States Geological Survey and administrator of the Smithsonian Institution. Ellis L. Yochelson cap-

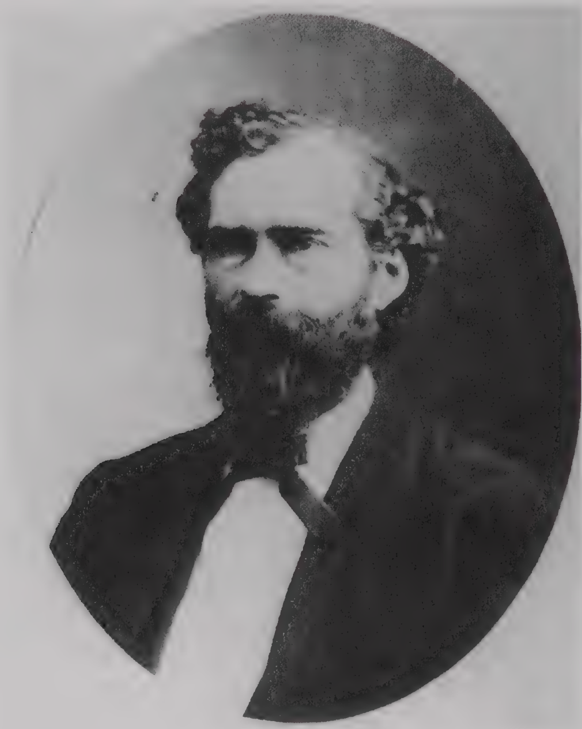


Figure 1: 1898 James R. Eastman, $1^{st}$ President of WAS
(Photo credit: Ref. 8)

tured his biography in the book, Charles Doolittle Walcott, Paleontologist.[2] The third president of WAS, Frank W. Clarke, called the "Father of Geochemistry" is credited with determining the composition of the Earth's crust (Figure 3). For the next several decades, the presidency continued to change annually (Table 1).

## Diversification Started in 1955

Dr. Margaret Pittman was the first female president of the Academy in 1955 (Table 2, Figure 4). She was a pioneering bacteriologist who conducted research at the National Institutes of Health (NIH). Subsequently, in 1957, she was named Chief of the Laboratory of Bacterial Products – she was the first woman to lead a NIH laboratory. Dr. Pittman was a key NIH participant in developing standards for cholera vaccine in the Southeast Asia in a region that is now Bangladesh.

Figure 2: 1899-1910 Charles Doolittle Walcott, $2^{nd}$ President of WAS (Photo credit: Ref. 9)

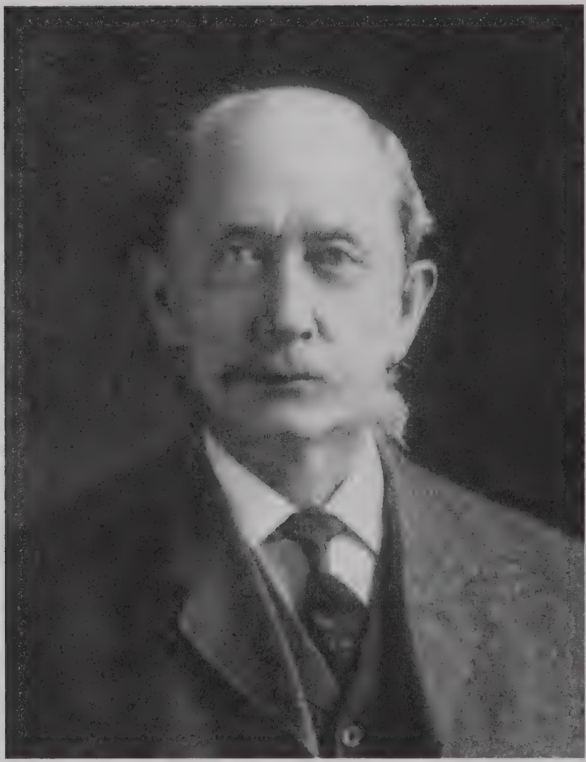


Figure 3: 1911 Frank Wigglesworth Clarke, $3^{rd}$ President of WAS
(Photo credit: Ref. 10)

Figure 4: Margaret Pittman, President of WAS in 1955
(Photo credit: Ref. 11)

Figure 5: Mary Louise Robbins, President of WAS 1971-1972
(Photo credit: Ref. 4)

Mary Louise Robbins was the second female president of WAS. She served as president from 1971 to 1972 (Table 3, Figure 5). She was a Professor in the Department of Microbiology in School of Medicine at George Washington University. She received a WAS Special Award for excellence and dedication to teaching as well as meritorious public service to science in the Washington area in 1977.[4] Under her leadership, the Academy held an important symposium entitled, "The Fate of the Chesapeake Bay".[5] Robbins retired to Japan where she volunteered in a program to help Japanese scientists write their research findings in English for publication in English language journals. She was much loved by her students and friends in Japan, as well as the United States.

Figure 6: John G. Honig, President of WAS 1981-1982
(Photo credit: Ref. 12)

In the next decade, John G. Honig (Figure 6) became president. He was born in 1923 in Austria.[7] Following Hitler's invasion of Austria, he fled to London alone, at the age of 15. Later, in 1940, he came to New York City with his parents and then moved to D.C. in 1949. He recently departed this world in 2020 at the age of 96 after a long and successful career. Honig was a physical chemist with the former National Institute of Cleaning and Dyeing and with the Naval Research Laboratory as well as several defense agencies.

In the decade after, Frank Rawle Haig, S.J. (Figure 7) became president. He is an American Jesuit priest, physicist, and academic administrator. He is also the younger brother of Alexander Haig, who served as the United States Secretary of State under Ronald Reagan from 1981 until 1982, and he gave generously to WAS and its mission.

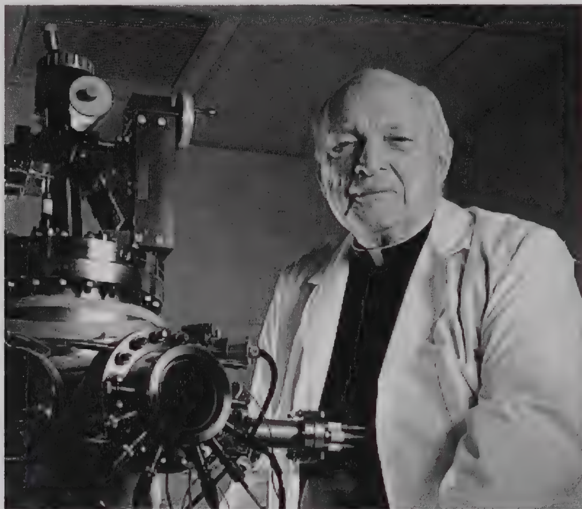


Figure 7: Frank Rawle Haig, S.J., President of WAS 1995-1996
(Photo credit: David Rehor)

**The Centennial Period**

Rita R. Colwell is Distinguished University Professor at the University of Maryland at College Park and Johns Hopkins Bloomberg School of Public Health and President of CosmosID, Inc. As an American microbiologist, her interests are focused on global infectious diseases, water, and health. She has authored or co-authored 20 books and more than 800 scientific publications. Colwell was elected WAS President (for 1996-1997) (Figure 8) after having served as President of the American Association for the Advancement of Science (AAAS). She then agreed to serve a second consecutive term as President (1997-1998), further showing her dedication to the Academy, after the President-Elect (Benjamin H. Alexander) unexpectedly passed away.i During her terms as President of the WAS, Colwell organized a series of seminars focused on local area research programs and workshops for young scientists of the region.

Michael P. Cohen was President of the Academy from 2003 to 2004 (Figure 9) when he was the Assistant Director for Survey Programs at the U.S. Bureau of Transportation Statistics. During Cohen's term as President, the Academy organized and held its highly successful first Capital Science Conference. Cohen is now a Principal Statistician at the American Institutes for Research. Cohen continues to serve on the Board as the

Figure 8: Rita R. Colwell, President of WAS 1996-1998
(Photo credit: R. R. Colwell)

Figure 9: Michael P. Cohen, President of WAS 2003-2004
(Photo credit: M. P. Cohen)

Representative of the Washington Statistical Society.

Peg Kay was President of Vertech, Inc. a telecommunications consulting company. She served as President (2004-2005) and later as Executive Director of WAS (Figure 10). She organized five biennial Capital Science conferences, nine Annual Awards ceremonies, and managed much of the ongoing work of the Academy.

## Recent Years

The most recent years, since 2000, indicate annual changes in the presidency (Table 4). Sue Cross served as President from 2017 to 2018. Cross' focus was communication, outreach to students, strengthening the Academy's connection with Affiliated Societies, expansion in the biomedical field, and recognition of scientists. Judy Staveley (Figure 11) served as

Figure 10: Peg Kay, President of WAS 2004-2005 (Photo credit: WAS)

President from 2019 to 2020 while being a Program Manager contractor for the U.S. Air Force. During Dr. Staveley's term as President, she organized and held online virtual scholarly lectures during the 2020 pandemic, held mentoring sessions for science students, and attended national speaking engagements to promote the Academy. Additionally, she was an honorable speaker on behalf of the Academy on Capitol Hill for the S-STEM symposium hosted by AAAS and the National Science Foundation to speak on science mentorship, retaining underrepresented students in sciences, and creating pathways to an inclusive workforce. She continues to serve WAS as a Member at Large Board Member.

Mina Izadjoo (Figure 12) served as President three times, 2015 to 2016, 2018 to 2019, and most recently from 2021 to 2022. As such, she is the second longest serving President next to Walcott. Izadjoo continues to serve on the Board as a Member at Large.

Ram Sriram (Figure 13) is the immediate past president, with his tenure as President from 2021 to 2022. He is credited with championing WAS membership for non-residents, i.e., scientists living outside the capital

Figure 11: Judy Staveley, President of WAS 2019-2020
(Photo credit: J. Staveley)

Figure 12: Mina Izadjoo, President of WAS 2015-2016, 2018-2019, and 2021-2022 (Photo credit: WAS)

Figure 13: Ram Sriram, President of WAS 2021-2022
(Photo credit: WAS)

region. He recruited a new journal editor, Ken Baclawski (when the previous editor stepped down after 20 years of service). Additionally, Sriram oversaw the negotiations and office move within the AAAS building.

After Sriram, I became the next president. My key connections to the Academy were recognition with a WAS Leadership in Science Award (in 2018) and subsequently serving as Secretary of WAS (in 2018 through 2019). However, the past presidents directly laid the groundwork for my term. As I reflect on the first half of my presidency, change comes to mind since WAS now has six new board members. Additionally, the board has worked together to update and modernize some of the board basics (registration, finances, procedures, communications and revision to bylaws). In a few months, I will pass the gavel to Mahesh Mani, and I am confident that he will do a great job contributing further to WAS' mission.

## Relevant Journal Articles in Last Quarter-century

Regularly issues of Journal of the Washington Academy of Sciences include information about WAS events, people, and their strategies. A sampling of such articles is presented mostly for the past 25 years:

Figure 14: Lynnette D. Madsen, President of WAS 2022-2023
(Photo credit: E. B. Svedberg)

Before 1998

| | |
|---|---|
| • Past Presidents of the Washington Academy of Sciences | Vol. 82, No. 4, December, 1992 |
| • The Washington Academy of Sciences: Background, Origin, and Early Years | Vol. 84, No. 4, December, 1996 |
| • President's Report | Vol. 85, No. 3, December, 1998 |
| • Special Centennial Issues | Vol. 85, No. 2, December, 1998<br>Vol. 85, No. 1, December, 1998 |
| • Centennial Celebration Symposium Issue | Vol. 87, No. 1/4, October, 2001 |
| • The Junior Academy "STARS" Program | Vol. 88, No. 2, June, 2002 |

2003-2007

| | |
|---|---|
| • Where Science is Headed – Sixteen Trends: Presented at the Meeting of the Affiliated Societies of the Washington Academy of Sciences | Vol. 89, No. 3/4, Fall/Winter, 2003 |
| • A Change in Editorship | Vol. 89, No. 1/2, Spring/Summer, 2003 |
| • Presidential Message; Capital Science<br>• Surrounded By Science – Growing Up In The Nation's Capital<br>• Science Before and After September 11 | Vol. 90, No. 2, Summer 2004 |
| • Report of The Nanotechnology Forum of The Washington Academy of Sciences<br>• How The Washington Academy of Sciences Helps Its Members Participate in The City's Science Community | Vol. 91, No. 4, Winter 2005 |
| • Presidential Message<br>• The Role of Academies of Science in the Critical Examination of New Ideas: Looking at Gaia | Vol. 92, No. 2, Summer 2006 |
| • Science Has No Gender – The History of Women in Science<br>• Presidential Remarks | Vol. 93, No. 1, Spring 2007 |
| • Annual Awards | Vol. 93, No. 2, Summer 2007 |

2008-2012

| | |
|---|---|
| • Thank God For The Journal Of The Academy! Scientific Publications During World War II | Vol. 94, No. 3, Fall 2008 |
| • Presidential Remarks, Capital Science, Annual Awards | Vol. 94, No. 2, Summer 2008 |
| • Science Policy | Vol. 95, No. 3, Fall 2009 |
| • Presidential Remarks, Annual Banquet | Vol. 95, No. 2, Summer 2009 |
| • Science is Murder, Capital Science | Vol. 96, No. 1, Spring 2010 |
| • Banquet and Presidential Remarks | Vol. 96, No. 2, Summer 2010 |
| • Science Is Murder | Vol. 97, No. 1, Spring 2011 |
| • Outgoing President's Remarks; Annual Awards | Vol. 97, No. 2, Summer 2011 |
| • Dedicatory Gift for the Washington Academy of Sciences | Vol. 97, No. 3, Fall 2011 |
| • Presidential Remarks & Annual Awards | Vol. 98, No. 2, Summer 2012 |

2013-2017

| | |
|---|---|
| • Presidential Remarks, Board Members | Vol. 99, No. 1, Spring 2013 |
| • Annual Awards | Vol. 99, No. 3, Fall 2013 |
| • Past President Dr. John H. Proctor (1931 – 2013) | Vol. 99, No. 4, Winter 2013 |
| • Annual Awards | Vol. 100, No. 2, Summer 2014 |
| • Annual Awards | Vol. 101, No. 1, Spring 2015 |
| • The Journal of the Washington Academy of Sciences joins the JSTOR Archive | Vol. 101, No. 4, Winter 2015 |
| • Messages from Presidents, Annual Awards | Vol. 102, No. 2, Summer 2016 |
| • Annual Meeting and Awards Banquet | Vol. 103, No. 2, Summer 2017 |
| • A Brief History of the WAS Junior Academy | Vol. 103, No. 4, Winter 2017 |

2018-2022

| | |
|---|---|
| • Messages from Presidents, Annual Awards | Vol. 104, No. 2, Summer 2018 |
| • Comments from the Vice President for Administrative Affairs | Vol. 104, No. 4, Winter 2018 |
| • Annual Awards | Vol. 105, No. 2, Summer 2019 |
| • Beyond the Classroom | Vol. 106, No. 1, Spring 2020 |
| • Annual Awards, President Speeches | Vol. 106, No. 3, Fall 2020 |
| • Annual Awards, President Speeches | Vol. 107, No. 3/4, Winter 2021 |
| • James Filliben Obituary | Vol. 108, No. 2, Summer 2022 |
| • Annual Awards, President Speeches | Vol. 108, No. 2, Summer 2022 |

## Conclusions

I am impressed with the Academy. WAS has had many remarkable leaders: attested by their independent historical records and accomplishments in science and/or in the policy-education landscape. WAS has recorded the thoughts of these leaders across many decades in their journal which has facilitated WAS' positive evolution. Moreover, the journal has embraced scientific research, communication and policy broadly allowing for expression of current thought and scholarship. All of these aspects bode well for WAS serving the community for another 125 years.

## Acknowledgements

I am grateful to many for making this historical compilation possible. First to the many editors of the Journal of the Washington Academy of Sciences for their records, particularly Kenneth P. Baclawski. My appreciation also extends to Michael P. Cohen and Rita R. Colwell for sharing their stories, Paul Averson for keeping board minutes, and Mark Spradley for highlighting the need to celebrate the quasquicentennial. I am also grateful to the past presidents who supplied their biographies and photographs. Lastly, I am thankful to Mahesh Mani for encouraging me to write this article and Sethanne Howard for hammering home that the journal is the archive of WAS and her helpful suggestions on this article.

## References


1. Ellis L. Yochelson (1996). The Washington Academy of Sciences: Background, Origin, and Early Years, *Journal of the Washington Academy of Sciences*, 84(4), 184–220.

2. Ellis L. Yochelson (1998). *Charles Doolittle Walcott, Paleontologist*, The Kent State University Press.

3. Past Presidents of the Washington Academy of Sciences (1992). *Journal of the Washington Academy of Sciences*, 82(4), 207.

4. The Awards Program of The Academy and Recent Honorees (1977). *Journal of the Washington Academy of Sciences*, 67(2), 86–90.

5. Mary Louise Robbins (1972). Welcome, *Journal of the Washington Academy of Sciences*, 62(2), 51–52. Symposium Issue.

6. John Honig (n.d.). Obituary. https://bit.ly/3NmZN8y

7. Benjamin H. Alexander Dies (1997). *The Washington Post*, Feb. 19, 1997.

8. Smithsonian Institution Archives, Record Unit 7099, Box 32. Negative No. 97-1690

9. Smithsonian Institution Archives, Record Unit 95. Negative No. 82-3143

10. Smithsonian Institution Archives, Record Unit 7099, Negative No. 97-1692

11. Margaret J. Pittman. Digital Commons @ RU. https://bit.ly/3NoVERt

12. John Honig. The Washington Post. https://bit.ly/41hm39M

Table 1: Presidents[3] in the Earliest Years

| | |
|---|---|
| 1898 James R. Eastman | 1925 Vernon Kellogg |
| 1899-1910 Charles D. Walcott* | 1926 George Kimball Burgess* |
| 1911 Frank W. Clarke* | 1927 Alexander Wetmore* |
| 1912 Frederick Vernon Coville* | 1928 Robert B. Sosman |
| 1913 Otto Hilgard Tittmann* | 1929 Aleš Hrdlička* |
| 1914 David White | 1930 William Bowie* |
| 1915 Robert Simpson Woodward* | 1931 Nathan Cobb |
| 1916 Leland Ossian Howard* | 1932 Leason Heberling Adams* |
| 1917 William Henry Holmes* | 1933 Robert Fiske Griggs* |
| 1918 Lyman James Briggs* | 1934 Louis B. Tuckerman |
| 1919 Frederick Leslie Ransome* | 1935 George W. McCoy |
| 1920 Carl L. Alsberg* | 1936 Oscar Edward Meinzer* |
| 1921 Alfred Hulse Brooks* | 1937 Charles Thom* |
| 1922 William Jackson Humphreys* | 1938 Paul E. Howe |
| 1923 Thomas Wayland Vaughan* | 1939 Charles E. Chambliss |
| 1924 Arthur I. Day | |

* Wikipedia entry

Table 2: Presidents[3] in the 40's, 50's and 60's

| | |
|---|---|
| 1940 Eugene C. Crittenden*<br>1941 Austin Hobart Clark*<br>1942 Harvey L. Curtis<br>1943 Leland W. Parr<br>1944 Clement L. Garner<br>1945 John E. Graf<br>1946 Hugh Latimer Dryden*<br>1947 Waldo LaSalle Schmitt*<br>1948 Frederick Dominic Rossini*<br>1949 F. H. H. Roberts, Jr.<br>1950 Francis B. Silsbee<br>1951 Nathan R. Smith<br>1952 Walter Ramberg<br>1953 Frank M. Setzler<br>1954 Francis M. Defandorf<br>1955 Margaret Pittman* | 1956 Ralph E. Gibson<br>1957 William M. Rubey<br>1958 Archibald T. McPherson<br>1959 Frank L. Campbell<br>1960 Lawrence A. Wood<br>1961 Philip Hauge Abelson*<br>1962 & 1963 Benjamin D. Van Evera (double term)<br>1964 François Naftali Frenkiel*<br>1965 Leo Schubert<br>1966 John K. Taylor<br>1967 & 1968 Heinz Specht (double term)<br>1968-69 Malcolm Henderson<br>1969-70 George W. Irving, Jr. |

* Wikipedia entry

Table 3: Presidents[3] in the 70's, 80's and 90's

| | |
|---|---|
| 1970-1971 Alphonse F. Forziati | 1986-1987 Simon W. Strauss |
| 1971-1972 Mary L. Robbins | 1987-1988 Ronald W. Manderscheid |
| 1972-1973 Richard K. Cook | 1988-1989 James E. Spates |
| 1973-1974 Grover C. Sherlin | 1989-1990 Robert H. McCracken |
| 1974-1975 Kurt H. Stern | 1990-1991 Armand B. Weiss |
| 1975-1976 George Abraham | 1991-1992 Walter E. Boek |
| 1976-1977 Florence H. Forziati | 1992-1993 Stanley G. Leftwich |
| 1977-1978 Richard H. Foote | 1993-1994 John H. Proctor, |
| 1978-1979 Mary H. Aldridge | 1994-1995 Rev. Frank R. Haig, S.J.* |
| 1979-1980 Alfred Weissler | 1995-1996 John S. Toll* |
| 1980-1981 Maijorie R. Townsend* | 1996-1998 Rita R. Colwell* (double term) |
| 1981-1982 John G. Honig | 1998-1999 Cyrus R. Creveling |
| 1982-1983 James F. Goff | 1999-2000 Rex Klopfenstein |
| 1983-1984 Jean K. Boek | |
| 1984-1985 Ralph I. Cole | |
| 1985-1986 John J. O'Hare | |

* Wikipedia entry

Table 4: Presidents from year 2000 onwards

| | |
|---|---|
| 2000-2001 W. Allen Barwick | 2014-2015 Terrell Erickson |
| 2001-2002 Jorome Gibbon | 2015-2016 Mina Izadjoo |
| 2002-2003 Marilyn R. London | 2016-2017 Mike Coble |
| 2003-2004 Michael P. Cohen | 2017-2018 Sue Cross |
| 2004-2005 Peg Kay | 2018-2019 Mina Izadjoo (second time) |
| 2005-2006 F. Douglas Witherspoon | 2019-2020 Judy Staveley |
| 2006-2007 William Boyer | 2020-2021 Mina Izadjoo (third time) |
| 2007-2008 Alain Touwaide | 2021-2022 Ram Sriram |
| 2008-2009 Albert H. Teich | 2022-2023 Lynnette Madsen |
| 2009-2010 Kiki Ikossi | 2023-2024 Mahesh Mani (incoming president) |
| 2010-2011 Mark Holland | |
| 2011-2012 Gerard Christman | |
| 2012-2013 Jim Cole | |
| 2013-2014 Jim Egenrieder | |

**LYNNETTE D. MADSEN**, Ph.D., is a material scientist and engineer. She has published two books, three book chapters/sections, and more than 100 articles; been awarded three patents; and delivered more than 100 invited talks. She is a Fellow of the Washington Academy of Sciences, American Association for the Advancement of Science, American Ceramic Society, American Vacuum Society, Materials Research Society and ASM International, and is a Senior Member of the Institute of Electrical and Electronics Engineers. She currently serves on the Advisory Board for the Rosalind Franklin Society and editorial board for Materials Today. Dr. Madsen was recognized with a WAS Leadership in Science Award (2018) and subsequently served as Secretary of WAS (2018-2019) and President of WAS (2022).

# Is a Greenhouse Heated by Radiation Trapping or Convection Blocking?

Paul T. Arveson
Washington Academy of Sciences

## Abstract

In the climate science literature, there are many references to an experiment performed by Prof. R. W. Wood in 1909 which led him to conclude that the main cause of heating in a greenhouse is by blocking air convection. Based on Wood's article, global warming skeptics have argued that the "greenhouse effect" due to trapping of radiation by the atmosphere is false. It seems strange that a brief note published over a century ago should continue to be invoked to cast doubt on climate science today. This article reviews recent efforts to replicate Wood's experiment (including new ones I conducted) and concludes that Wood was mistaken. The "greenhouse effect" – at least as applied to a real greenhouse – is heated primarily by selective filtering of infrared radiation.

## Introduction

THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) is the United Nations body for assessing the science related to climate change. Since 1990 the IPCC has assembled large working groups of scientists across the world to provide the most reliable account of the Earth's climate and its changes. Throughout the IPCC reports, the blame for recent global warming and climate change is traced to increased "greenhouse gases" in the atmosphere. The work of Fourier in the 1820s is cited as the origin of the "greenhouse effect" analogy which explains heating in a real greenhouse. In Fourier's account, solar radiation enters through the transparent glass, but because glass is opaque to infrared light, radiation emitted from the warm ground gets trapped [1].

It is important to clarify whether the greenhouse analogy is valid or not. The reason is that numerous climate skeptics have sought to refute the main claims of the IPCC based on an alleged failure of the analogy. Skeptics frequently cite a brief note from 1909 by Professor Robert W. Wood of Johns Hopkins University [2] to make their case. Wood doubted Fourier's theory based on radiation trapping. He performed an experiment

comparing boxes with a pane of glass and a pane of crystallized rock salt (sodium chloride) which is transparent to infrared radiation. Since he found no difference in temperature, he concluded that greenhouses work merely by preventing convection, a mechanism that is not applicable to the open atmosphere. Based on Prof. Wood's conclusion, skeptics argue that the atmosphere doesn't warm the earth due to radiation trapping, and the "greenhouse effect" analogy to the atmosphere is erroneous.

Here are some dramatic headlines of recent articles making this point:
"Greenhouse Gas Theory Trashed in Groundbreaking Lab Experiment" [3]
"New Paper Discrediting Basis of Theory of Man-Made Global Warming"[4]
"The Shattered Greenhouse: How Simple Physics Demolishes the 'Greenhouse Effect"' [5]
"The Fraud of the Atmospheric Greenhouse Effect" [6]
"R.W. Wood Had it Right: Sun Heats Earth!" [7]

Even among some mainstream scientists, acceptance of Wood's conclusion is apparently widespread. Here are some examples:

National Oceanography and Atmospheric Administration (NOAA):

> Note: This atmospheric process is referred to as the Greenhouse Effect, since both the atmosphere and a greenhouse act in a manner which retains energy as heat. However, this is an imperfect analogy. A greenhouse works primarily by preventing warm air (warmed by incoming solar radiation) close to the ground from rising due to convection, whereas the atmospheric Greenhouse Effect works by preventing infrared radiation loss to space. Despite this subtle difference, we refer to this atmospheric process as the Greenhouse Effect and these gases as Greenhouse Gases because of their role in warming the Earth.[8]

American Chemical Society:

> The atmospheric gases and a greenhouse work in quite different ways, but the resulting effect, higher temperature in both cases, has led to the nomenclature "greenhouse gases" for the

> atmospheric gases responsible for the atmospheric warming effect. Although this nomenclature is misleading, it is in such common use that we use it here as well. [9]

American Institute of Physics:

> The key publication explaining that greenhouses are kept warm less by the radiation properties of glass than because the heated air cannot rise and blow away; see Wood (1909); for the science... [10]

Even Carl Sagan disputed the greenhouse analogy in his famous global warming testimony before Congress in 1985, in which he defended the greenhouse effect in the atmosphere but added that "It is a misnomer because that is not how a florist's greenhouse works, but that's a very minor point." [11][1]

There are also abundant YouTube videos on the greenhouse effect, of varying quality.

It seemed strange to me that a brief article published over a century ago should continue to cast doubt or confusion considering today's massive efforts in climate science. I decided to review the literature on Wood's experiment and related experiments, then to conduct my own.

## Professor Wood's Experiment

Prof. Wood's greenhouse experiment appears simple enough. Here is the section of Wood's article that describes his experiment and its result:

> To test the matter I constructed two enclosures of dead black cardboard, one covered with a glass plate, the other with a plate of rock-salt of equal thickness. The bulb of a thermometer was inserted in each enclosure and the whole packed in cotton, with the exception of the transparent plates which were exposed. When exposed to sunlight the temperature rose gradually to

[1] At 4:40 Sagan stated correctly that the atmosphere is opaque at 15 microns. So is glass, by the way.

> 65 C., the enclosure covered with the salt plate keeping a little ahead of the other, owing to the fact that it transmitted the longer waves from the sun, which were stopped by the glass. In order to eliminate this action the sunlight was first passed through a glass plate.
>
> There was now scarcely a difference of one degree between the temperatures of the two enclosures. The maximum temperature reached was about 55 deg. C. From what we know about the distribution of energy in the spectrum of the radiation emitted by a body at 55 deg. C., it is clear that the rock-salt plate is capable of transmitting practically all of it, while the glass plate stops it entirely. *This shows us that the loss of temperature of the ground by radiation is very small in comparison to the loss by convection*, in other words that we gain very little from the circumstance that the radiation is trapped.
>
> Is it therefore necessary to pay attention to trapped radiation in deducing the temperature of a planet as affected by its atmosphere? The solar rays penetrate the atmosphere, warm the ground which in turn warms the atmosphere by contact and by convection currents. The heat received is thus stored up in the atmosphere, remaining there on account of the very low radiating power of a gas. It seems to me very doubtful if the atmosphere is warmed to any great extent by absorbing the radiation from the ground, even under the most favourable conditions. [Italics mine.]

Notice that Wood's article concerns two distinct questions:

1. What is the mechanism of heating in a greenhouse – blocking convection or trapping radiation?

2. What is the mechanism of global warming in the atmosphere?

Wood's experiment only directly addresses question 1. The analogy to the atmosphere is only valid if heating in both cases is due primarily to radiation trapping. Simple experiments only can address the first question, and Wood's answer is that radiation trapping is **not** the main mechanism of

heating a greenhouse. The physics of atmospheric heating is clearly much more complex and will not be addressed here; an excellent brief review of the theory is provided by Pierrehumbert (although he too denied the analogy to a greenhouse). [12]

### Experimental Tests of Wood's Conclusion

Interestingly, a critique of Wood's conclusion was published already *in the same year, in the same journal*, by C.G. Abbot, Director of the Smithsonian's Astrophysical Observatory. [13] He questioned the conclusion that heat loss was mainly due to convection. To reduce convective heat loss, he made a triple-glazed cover for a box on the ground. On a clear November day in 1909, Abbot measured the internal temperature. He also used Planck's blackbody radiation formula to calculate the heat balance of this setup and concluded that "...there is reason to think that 'trapping' is more important perhaps than Professor Wood thinks."

Dr. Abbot did not use a control, but his use of triple glazing was an elegant way to reduce convection and test Wood's conclusion. Another difference from Wood's experiment was the presence of the ground. Wood's insulated boxes had no mass load to absorb heat. This meant that the temperature in his boxes was dependent on the precise position of the thermometers and could vary due to stratification of heated air. If one intends to simulate the mechanism of warming of the Earth with a tabletop experiment, it is necessary to include something that simulates the ground!

It would seem that a retraction or at least further study was in order. But I could find no further discussion of this question between Wood and Abbot in the literature.

More recently other experimenters have attempted to replicate Wood's experiment, with modifications. For one thing, it is very problematic to use salt as a window – it is fragile and difficult or costly to obtain in clear form. Nowadays it is unnecessary to use a window made of salt to provide transparency in the infrared; polyethylene (PE) is a much more convenient substitute. It is essentially transparent in the infrared to beyond 20 microns, except for a few narrow bands. Polyvinylidene chloride film (PVC, food wrap) is another useful option. Figure 1 shows the infrared spectral transmittance of these films.

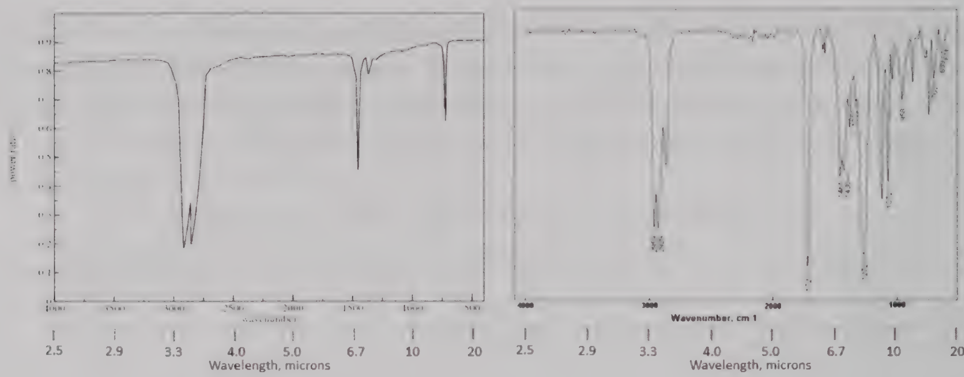



Figure 1: Infrared transmittance of polyethylene and polyvinylidene chloride films (ref. [14] and [15])

## Pratt's experiments

In 2009 Vaughan R. Pratt, a Stanford University professor, posted his work on a web page. [16]

It was titled, "Wood's 1909 greenhouse experiment, performed more carefully." He noted that Wood's article was "seriously lacking in detail." Wood provided no dimensions, and no diagrams or graphs of temperatures.

Pratt observed strong thermal stratification of the air in the box, which is not surprising. This implies that it would be difficult to make meaningful air temperature measurements in any experiment: the readings of the sensors are very sensitive to their position: "The variation within the boxes dwarfs the variation between the boxes," thus making his experiment inconclusive regarding the first question. Pratt could not resolve the question with this apparatus, because it attempted to replicate Wood's misguided experimental setup that did not include a thermal load.

## Nahle's experiments

Nasif S. Nahle in Mexico attempted to "replicate" Wood's experiment and "verify" his conclusion.[17] His rather elaborate report has tables showing similar temperatures (within one degree) attained in the boxes for

all window conditions. I think what could explain this similarity is that air circulated inside the boxes and quickly heated up to the same equilibrium temperature in all cases. As in Wood's experiment, there was no thermal mass in the boxes, just air. So, all the boxes heated up very fast to about the same equilibrium temperature.

From Pratt's and Nahle's experiences we learn that it is not prudent to attempt to replicate Wood's experiment. It is only necessary to perform any experiment that resolves the specific question about the mechanism of heating in a greenhouse. All the attempted replications do is to show that Wood's setup is not able to answer this question decisively. The experimental design must be modified by including a thermal mass and replacing the salt window. Or an entirely different experiment, such as the one used by Abbot, may provide a clearer answer.

## Spencer's experiments

Meteorologist Roy Spencer has spent years discussing all aspects of the climate change questions in detail on his blog. On the question of the greenhouse effect, he even went to the trouble to study the question experimentally. He first quoted Wood's article in its entirety. Then he reviewed the experimental work of Pratt and Nahle. Spencer was not misled by Wood's faulty experimental design: "I'm more interested in doing the experiment the right way than in trying to replicate an experiment where so many details are missing, and we have better methods available anyway." [18]

Spencer realized that Wood's use of a salt window is unnecessary. Spencer used a comparison of insulated boxes covered with either clear food wrap or an acrylic ("plexiglass") sheet for his experiments. Acrylic is an absorber of IR, like glass. The composition of food wrap varies. Some is made of polyvinylidene chloride, which has some absorption bands in the IR, but is probably adequately transparent for this experiment. Spencer reported that "we clearly see the warming effect of the plexiglass. Even though the plexiglass only passes 92% of the visible sunlight, which by itself should cause cooler temperatures, its presence over one box causes that box to warm relative to the other box (or, you can say its absence

causes the other box to run cooler). This is how the 'greenhouse effect' works."

Spencer's experiment did not contain a thermal load in the boxes, and his time-series plots in varying sunlight are confusing. However, his conclusion is unequivocal: "convective inhibition cannot explain the warming effect of the plexiglass. It must be an infrared effect." [19]

## New Experiments

For the past several years, I have been conducting experiments to measure the performance of solar thermal cookers, which are household-scale devices for cooking food with concentrated solar radiation. In 2015 I participated in meetings of the Clean Cooking Alliance [20] to develop standards for power, efficiency, emissions, safety, and durability of cookstoves, including solar cookers [21, 22, 23, 24]. This work involved development of instrumentation and protocols for testing these devices, so it was straightforward to adapt these to address the question of the greenhouse effect.

My new experiments were not intended to replicate Wood's experiment, which was ill-conceived in some ways as discussed above. Rather, it was simply an attempt to understand the physics well enough to answer question no. 1: the mechanism of heating in a real greenhouse.

As in Spencer's experiments, I used two Styrofoam boxes for the comparison of two window materials: ordinary glass in one and thin polyethylene film in the other. I mounted the boxes on a tilt table so that they could be easily aimed in the Sun's direction and turned to maintain a nearly constant solar irradiation. To provide a thermal load (which was missing in previous experiments), in each box I included a thick copper plate (because copper has low heat capacity and high thermal conductivity). To speed up the heating further, I painted the interior of the boxes with Krylon #1602 Ultra Flat Black spray paint (emissivity greater than 0.96 from 2-5 microns [25]). I painted the plates with a special artist's black paint, which appears blacker than the Krylon paint at least in the visible spectrum [26].

I did adopt one feature of Wood's experiment that was sensible: I mounted glass plates above both boxes, in order that the incoming radiation into the boxes was pre-filtered to include only visible light and not the IR

radiation from the Sun. In this way, both black plates received nearly the same incoming radiation. This prevented a misleading conclusion due to IR from the Sun that might heat the box with polyethylene more than the box with the glass window. Also, the pre-filter glass sheets were mounted on standoffs above the boxes to allow free convection, and the sheets were tilted at a 45° angle so that any back-reflections from the boxes were deflected to the sky.

The sensors for the experiments consisted of pairs of thermocouples that were bolted to the centers of each of the black plates. These were connected to a datalogger via cables that reached into the boxes through a 2 cm hole in the lower side of each box. In other words, there was no attempt to seal the boxes against pressure (as one experimenter prescribed [27]). In effect, the solar radiation was intended to heat the interior of the boxes as in heating a room in a house. In such a situation, isostatic pressure applies. (Strangely, the thermodynamics of this ordinary process has only recently been derived from first principles [28].)

In addition to the plate thermocouples, an external instrument package (a "Stevenson box") was built to measure local solar irradiation, ambient temperature, and wind speed. Three pyranometers were included; two measured global horizontal irradiance (GHI) and one was mounted on the tilt table to measure global tilted irradiance (GTI). The pyranometers provided a quantitative measure of the solar power coming into the test boxes. [29]

Figures 2 and 3 show the typical experimental setup used for the experiments. Tables 1, 2 and 3 provide details on the dimensions of the test boxes and cover materials.

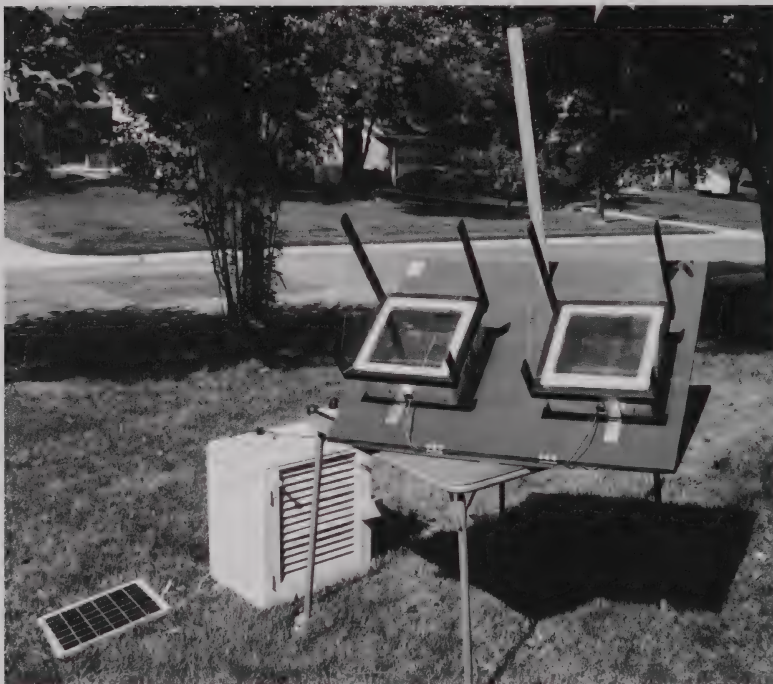


Figure 2: Experimental setup for comparison experiments. The white box is a "Stevenson box" containing weather instruments, powered by the solar panel on the ground. Each test box has a black frame holding a sheet of window glass at a 45° angle. Cables from 2 cm holes in the bottom of each box are connected to thermocouples to measure internal black plate temperatures. A data logger is connected to the cables behind the tilt table.

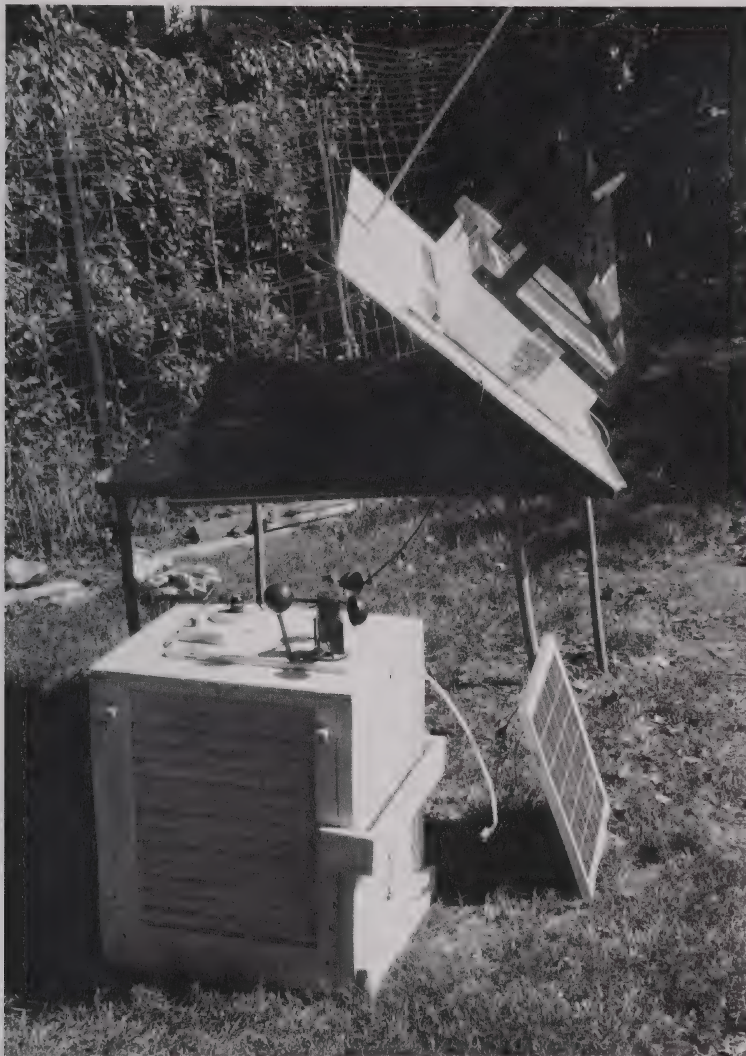


Figure 3: Side view of experimental setup showing two test boxes mounted on a tilt table to allow the boxes to be pointed in the Sun direction. Glass prefilter sheets can be seen mounted in frames in front of the boxes. There is a 4 cm air gap below the sheets to permit free convection over the boxes. A pyranometer is mounted on the tilt table for measuring global tilted irradiance (GTI), and two more are mounted on top of the Stevenson box to measure global horizontal irradiance (GHI), along with an anemometer. The Stevenson box also contains a solar panel charge converter and a data logger for storing measurements.

Table 1. Test apparatus materials

| Item | Material |
|---|---|
| Insulated boxes | Styrofoam |
| Mass load in each box | Copper |
| Glass box cover | Soda-lime glass |
| IR-transparent cover | Polyethylene film |
| IR-transparent cover | Polyvinylidene chloride |
| Tilt table | Plywood |
| Prefilter sheets (2) | Soda glass |
| Frames for prefilters (2) | Wood |

Table 2. Test apparatus dimensions

| Item | Dimensions, in | Dimensions, cm |
|---|---|---|
| Insulated boxes | 11.75 x 11.75 x 5.75 | 29.8 x 29.8 x 14.6 |
| Mass load in each box | 8 x 8 x 1/4 | 20.32 x 20.32 x .3175 |
| Glass box cover | 9.5 x 9.5 x 3/32 | 24.1 x 24.1 x .238 |
| IR-transparent cover | 0.00025 | 0.00063 |
| IR-transparent cover | 0.0003 | 0.0007 |
| Tilt table | 24 x 48 x 1/4 | 132 x 61 x .635 |
| Prefilter sheets (2) | 13 x 14.5 x 3/32 | 33 x 36.8 x .238 |
| Frames for prefilters (2) | 12 x 12 x 9.5 | 30.5 x 30.5 x 24.1 |

Table 3. Heat capacities of materials

| Item | Mass | Heat capacity, J/kg K |
|---|---|---|
| Copper plates, each | 1.179 kg | 385 |
| Glass cover (heated portion only) | 0.292 kg | 840 |
| Styrofoam box | 0.185 kg | 1215 approx. |

## Experimental Data

### Calibrations

Preliminary tests were done to ensure that thermocouple readings had small systematic errors. When cooled to ambient temperature

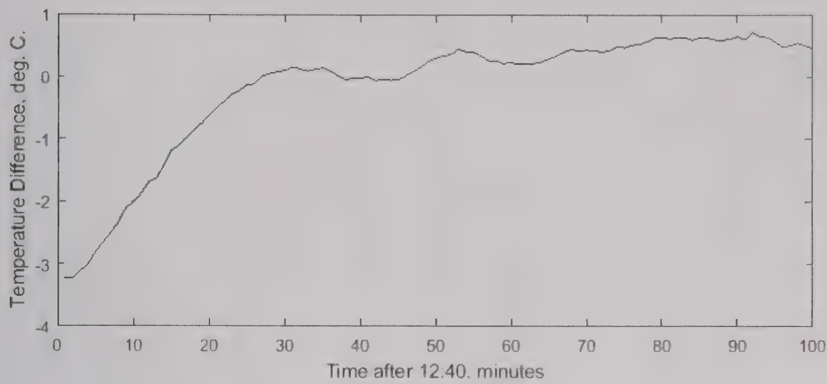



Figure 4: Differences between plate temperatures in two boxes with PE covers (Experiment 15).

overnight, temperature readings of all four thermocouples converged to within a range of 0.2° C.

## Controls

It was necessary to determine any temperature differences between the two boxes when they both had the same cover material. Control experiments were performed in which both boxes had polyethylene covers. These experiments showed minor temperature differences of less than 1° C once the boxes heated to equilibrium. Figure 4 shows a typical example of the temperature differences between the black plates in a control experiment.

## Comparisons

Once it was clear that the temperature measurements had adequately low systematic and random errors, comparison experiments could commence. These experiments were only done when the sky was clear and average wind speed was less than 1 m/s. Figure 5 shows a typical example of the heating curve for a comparison experiment. The upper curve shows the temperatures of the plate in the glass covered box; the lower curve is for the plate in the polyethylene covered box. Temperatures in both boxes

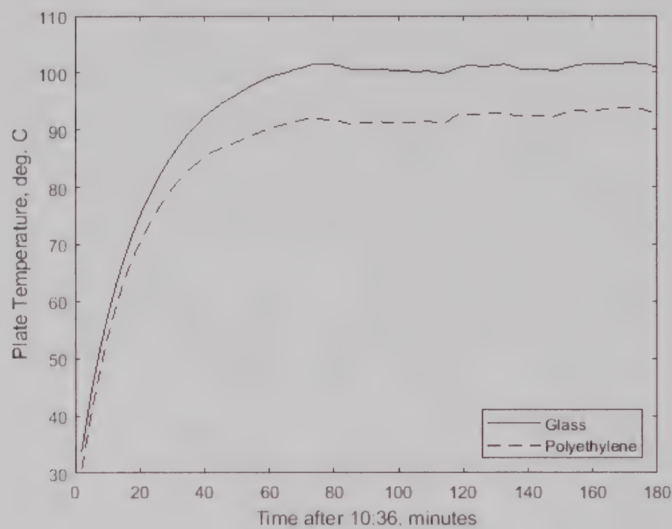



Figure 5: Plate temperatures in two test boxes for Experiment 18

rose to equilibrium in about 80 minutes. The typical difference in temperatures was 8 degrees C. Measurements were made over a range of ambient temperatures from 5° to 25° C, but the mean temperature differences were consistently 8 to 10 degrees C. The glass-covered box always had higher plate temperatures.

## Summary of Experimental Results

A series of experiments was conducted in the fall and winter of 2022-23. It was of interest to select clear days with high and low ambient temperatures. Table 4 shows a summary of the results of both the control and comparison experiments (nos. 1-13 were for setup and calibrations). Note that two of the comparisons were done without the prefilters in place; these experiments showed higher temperature differences, as would be expected. The main conclusion is that (with prefiltering) the glass-covered box was an average of 8 degrees C higher than the polyethylene (PE) film-covered box. This is significantly higher than the standard deviation of the differences in the controls, which was less than 1 degree C.

Table 4. Temperature Difference Data
Glass or PVC box minus PE box at Equilibrium, degrees C

| No. | Date | Conditions | Ambient | * | Difference |
|---|---|---|---|---|---|
| 14 | 20221006 | Control (2 PE boxes) | 26 | On | 2 |
| 15 | 20221007 | Control (2 PE boxes) | 28 | On | 0.5 |
| 16 | 20221009 | Comparison, glass vs. PE | 20 | On | 10 |
| 17 | 20221010 | Control (2 PE boxes) | 22 | On | ±2 |
| 16 | 20221009 | Comparison, glass vs. PE | 20 | On | 10 |
| 18 | 20221011 | Comparison, glass vs. PE | 25 | On | 8 |
| 19 | 20221021 | Comparison, glass vs. PE | 23 | Off | 13 |
| 20 | 20230211 | Comparison, glass vs. PE | 11 | Off | 12 |
| 21 | 20230214 | Comparison, glass vs. PE | 16 | On | 8.5 |
| 22 | 20230218 | Comparison, glass vs. PE | 5 | On | 8 |
| 23 | 20230223 | Comparison PVC vs. PE | 23 | On | 1 |

* Prefilters On/Off

As is evident from the control experiments, the boxes are very similar and capable of resolving differences of 1 degree C or less. It was consistently observed that the plate in the glass-covered box reaches higher temperatures than the polyethylene-covered box by 8 degrees C or more. This result was not significantly affected by ambient temperatures in the range from 5° to 25° C.

These empirical results could still be questioned, based on the obvious fact that they were not obtained from measurements of a real greenhouse. However, what is of interest here is not a greenhouse per se but the mechanism of heating in the "greenhouse effect," and this can be adequately studied using small boxes. Further understanding of the heating mechanisms can be sought via a mathematical model based on established thermodynamics theory.

## Simplified Thermodynamic Model of the Test Boxes

It will be instructive to consider a simple thermodynamic model of the experiment. The purpose of this section is not to derive a complete or rigorous model, but only enough to allow us to understand the relationships of the variables involved in heating and cooling, and to quantify the parameters that affect the heating of the test boxes.

Consider an insulated box with a window and an internal metal plate that is heated by the Sun. The energy input to the box includes solar radiation across the visible spectrum. Of course, the solar irradiance varies with time $t$ due to solar elevation, clouds etc. so we will just call it $G(t)$. For any object in the outside air, heat loss occurs by convection and radiation (loss due to conduction is included in the loss due to convection). Newton found that heat loss due to convection is proportional to the difference between an object's surface temperature $T$ and the ambient temperature $T_a$ (Newton's law of heating and cooling). In the late $19^{th}$ century, Stefan and Boltzmann found that radiation loss has a fourth power dependence on the temperature difference between the object's temperature and the temperature of the surrounding radiation from the sky $T_s$. Combining these two laws for heat change $dQ$ in Watts leads to a differential equation [30]:

$$dQ = mC_{\nu}\frac{DT}{dt} = G(t) - hA(T_a - T) - (A\epsilon\sigma T^4 - Aa\sigma T_s^4) \qquad (1)$$

Here, $m$ is the mass of the object, $C_{\nu}$ is the heat capacity of the object, $A$ is the area of the object exposed to the Sun and $h$ is the heat transfer coefficient for the object. The last term is the Sefan-Boltzmann equation for radiation loss, in which dimensionless parameters $\epsilon$ and $a$ are the emissivities of the object and the sky respectively, and $\sigma$ is the Stefan-Boltzmann constant, which is $5.67 \times 10^{-8}$W/m K.

If the "heated object" is really a system with various parts, a boundary can be placed around it, and this equation can still be used, provided the masses, heat capacities and other parameters can be combined and treated as one object with a characteristic size $L$, under the restriction that

$$Bi = hL/k < .002 \qquad (2)$$

where $Bi$ is the Biot number, and $k$ is the thermal conductivity of the object. In the case of an object with internal fluid circulation such as a greenhouse or a heated box, the conductivity can be assumed to be high, so under this restriction we can model the heating or cooling of the object with equation (1). This equation then represents the (simplified) transient lumped-parameter model of the test box. Since the dominant thermal load of the test box is in the black plate, the solution of this equation describes the overall change in temperature T(t) of that plate over time.

Equation (1) describes the functional relationships of the important variables by placing experiments into the context of well-established physical theory. This reduces into mathematical form the first question that Wood addressed: which term – convection or radiation – contributes more to the heating of an object like a greenhouse? We answered this question experimentally, but it is also helpful to examine it mathematically to quantify and generalize the conclusion.

## Convection loss from the glass window

As the test box is exposed to sunlight it is heated, and free convection draws energy away at a rate determined by the convection loss coefficient $h$. In estimating convective heat loss in the test boxes, what matters is the surface that is exposed to the ambient air, not the internal copper plate temperature. A rigorous calculation of the temperature of the glass would need to include the heat transfer from the internal plate through the glass to the ambient air – in other words, it would require a more complex calculation than the simplified lumped-parameter model. In mathematical terms, this is a conjugate problem [31].

Rather than pursue this calculation, I simply used a hand-held pyrometer to measure the temperature of the glass window. Pyrometer measurements at equilibrium showed temperatures of 42-47° C across the glass when the ambient temperature was 15° C. To first order, this is roughly halfway between the temperatures of the copper plate and the ambient.

A formula for $h$ for free convection over a heated vertical plate can be found in textbooks [32]. Such formulas are empirically derived correlations given in terms of the dimensionless Nusselt number $Nu$, or equivalently the Grashof number $Gr$ and the Prandtl number $Pr$. These numbers are based on properties of air and the plate dimensions. Substituting these values into the correlation formula for a 46° C vertical surface gives $h = 4.9$ W/m$^2$. This is similar to the plotted value of $h = 4$ at very low wind speed (0.1 m/s) in ISO standards [33, 34]. However, with the tilted ($\sim 50°$ from vertical) glass window in our experiments, these correlation formulas are likely to give only a rough approximation since the flow probably separates rather than forming a laminar boundary layer as assumed in correlation formulas. Also, slight wind drafts may increase the heat loss.

## Effect of wind speed on $h$

Clearly there will be some wind speed at which convection loss will exceed radiation loss. A worst-case calculation for the value of $h$ assumes that the wind is moving in the same direction as the free convection, i.e., this becomes a forced convection calculation. Formulas for the forced convection coefficient over a vertical flat plate are given in terms of a combination of the Reynolds number and the Prandtl number [35]. The Reynolds number is defined as $Re = uL/n$ , where $u$ is the flow velocity and $n$ is the kinematic viscosity. Using parameters of the experimental boxes, the heat loss balance between convection and radiation at equilibrium was calculated. These calculations show that for the glass-covered box, radiation dominates the heat loss up to an air flow velocity of 1.5 m/s; it would be somewhat higher for a tilted plate.

## Effect of scale on $h$

A full-scale greenhouse would obviously have a higher surface area $A$, but also a lower average value of $h$, since $h$ is inversely related to the length of a plate:

$$h = \frac{kNu}{L} \tag{3}$$

However, in seeking to scale up the mathematical model to the size of a real greenhouse, we encounter computational difficulties, because at larger scales the Biot number and Reynolds number restrictions are exceeded, and the convection is turbulent. These issues compound the problem of modeling a full-scale greenhouse. But full-scale calculations would use the same methods as do such calculations for the heating and cooling of any building or large structure. There is an abundance of literature available to address this general engineering problem, which goes beyond the scope of this article. As mentioned earlier, the question of interest here is not a greenhouse *per se* but the mechanism of heating in the "greenhouse effect."

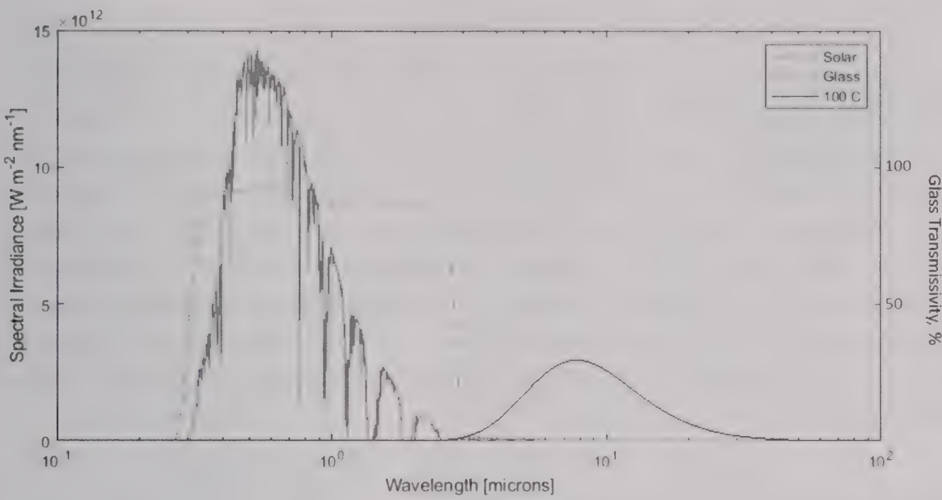



Figure 6: (a) Solar radiation at Earth's surface from [36], (b) transmissivity of window glass (right scale) from [37], (c) Planck blackbody radiation from internal plate at 100° C. (The blackbody radiation has been amplified by $10^5$ to increase its visibility on the plot).

## Radiation loss from the glass-covered box

Figure 6 shows the spectral data that are relevant to the discussion of radiation loss. Incoming solar radiation (a) is mostly transmitted through the glass (dashed curve (b)). But glass is opaque in the infrared, so the radiation from the internal black plate (c) is prevented from escaping. Infrared radiation from the plate heats the opaque glass, which radiates to the sky. As mentioned earlier, at equilibrium the measured temperature of the glass was about 42-47° C. This is much lower than that of the plate (about 100° C). In qualitative terms, the plate is partially "insulated" by the glass; its heat loss is reduced, so its temperature is higher. For the polyethylene-covered box, infrared radiation from the black plate goes directly to the sky. The plate in the glass-covered box cannot release this radiation, so it gets hotter.

## Conclusion

Confusion about the "greenhouse effect" analogy still pervades even well-intentioned literature that seeks to provide an accurate explanation of the mechanism of climate change. Although most scientists are not climate change skeptics, there are numerous references to the "greenhouse effect" in which the author assumes that the greenhouse analogy is false (recalling Wood's article from 1909) but that the atmosphere is nevertheless heated by the mechanism of radiation trapping. This confusion has been propagated in textbooks [38, 39], in a NOAA tutorial [8], an ACS tutorial [9], an AIP tutorial [10], references on Wikipedia [40], and even in the congressional testimony of Carl Sagan [11].

The experimental and theoretical results shown in this article demonstrate that the "greenhouse effect" *is* a correct analogy to the atmosphere: both are heated primarily by radiation trapping. Full acceptance of this analogy by the science community is long overdue.

## References

1. IPCC Sixth Assessment Report, Chapter 1: Framing, Context and Methods (ipcc.ch) p. 178. https://bit.ly/3s2Wmwi

2. Wood, R.W. (1909). Note on the Theory of the Greenhouse (Communicated by the Author), *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, Series 6, Vol. 17(98), 319-320. https://bit.ly/3McD8LE

3. Sullivan, J. (2011). "Greenhouse Gas Theory Trashed in Groundbreaking Lab Experiment," https://bit.ly/492RMPp

4. Anon., "New Paper Discrediting Basis of Theory of Man-Made Global Warming," https://bit.ly/40516yd

5. Casey, T. (2011). "The Shattered Greenhouse: How Simple Physics Demolishes the 'Greenhouse Effect'." https://bit.ly/3QrWsam

6. Postma, J.E. (2012). "The Fraud of the Atmospheric Greenhouse Effect" https://bit.ly/408xP5G

7. Postma, J.E. (2016). "R.W. Wood Had it Right: Sun Heats Earth!" https://bit.ly/40a47gv

8. "Basics of the Carbon Cycle and the Greenhouse Effect" https://bit.ly/40cBPC7

9. Anon., (2012), Greenhouse Gases, ACS Climate Science Toolkit, American Chemical Society, https://bit.ly/406LDh8

10. Weart, S. (2022). "The Discovery of Global Warming," American Institute of Physics, https://bit.ly/406HVUu

11. Sagan, C. (1985). Testimony before Congress, https://bit.ly/406M2QG

12. Pierrehumbert, R.T. (2011). "Infrared radiation and planetary temperature," *Phys. Today* 64(1), 33 (2011); doi: 10.1063/1.3541943. https://bit.ly/3SbY7BX

13. Abbot, C.G. (1909) V. "Note on the theory of the greenhouse," *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 18:103, 32-35 https://bit.ly/406XTy2

14. Ruxanda, B., Teacă, C. A., Spiridon, I. (2009). Preparation and characterization of composites comprising modified hardwood and wood polymers/poly(vinyl chloride), *Bioresources* 4(4), Nov. 2009. DOI: 10.15376/biores.4.4.1285-1304.

15. Jaffer, A. (2019). FreeSnell: Polyethylene, https://bit.ly/46F3M8b

16. Pratt, V.R. (undated). "Wood's 1909 greenhouse experiment, performed more carefully," https://bit.ly/40cBUWr

17. Nahle, Nasif S. (2011). Repeatability of Professor Robert W. Wood's 1909 experiment on the Theory of the Greenhouse, July 5, 2011. *Biology Cabinet Online-Academic Resources and Principia Scientific International.* Monterrey, N. L. https://bit.ly/405Veor

18. Spencer, R. (2013). "Revisiting Wood's 1909 greenhouse box experiment, Part I," https://bit.ly/3Sb8nus

19. Spencer, R. (2013). "Revisiting Wood's 1909 greenhouse box experiment, Part II," https://bit.ly/3Qcnz7Q

20. Clean Cooking Alliance, https://cleancooking.org/

21. Arveson, P.T. (2016). "Towards an international standard for measuring solar cooker performance," J. Wash. Acad. Sci. 102(3), Fall 2016. https://bit.ly/3Q7mdv9

22. Anon., (2013). "Testing and reporting solar cooker performance," ASAE S580.1, American Society of Agricultural Engineers. https://bit.ly/45NT1PA

23. ISO 19867-1:2018, Clean cookstoves and clean cooking solutions - Harmonized laboratory test protocols - Part 1: Standard test sequence for emissions and performance, safety, and durability. https://bit.ly/3Q7me2b

24. ISO 19869:2019, Clean cookstoves and clean cooking solutions — Field testing methods for cookstoves. https://bit.ly/493DrlL

25. Huynh, M. (2018). "Analyzing Reflectance Data for Various Black Paints and Coatings," NATO STO-MP-SET-277, https://bit.ly/45Jwa7T

26. https://bit.ly/3Q10CEs

27. Shmaefsky, B. (2004). Favorite demonstrations for college science: an NSTA

Press journals collection. NSTA Press. p. 57. ISBN 978-0-87355-242-4. Archived from the original on 2 August 2020. Retrieved 18 February 2016. https://bit.ly/3QtvDCs

28. Kreuzer, H.J. and Payne, S.H. (2011). Thermodynamics of heating a room, American J. of Physics 79, 74 (2011); https://bit.ly/499agh5

29. Arveson, P.T. (2018). A system for standard power measurements of solar cookers based on commercial off-the-shelf instruments, SHE Technical Report TR-09.1, Apr. 2018. https://bit.ly/3Qthvt1

30. Shih, Tien-Mo. (2012). Heat Transfer: Lessons with examples solved by Matlab. Cognella, Inc. (2012). ISBN: 978-1-60927-544-0, p. 269.

31. Dorfman, A.; Renner, Z. (2009). Conjugate Problems in Convective Heat Transfer: Review, *Mathematical Problems in Engineering*, vol. 2009, Article ID 927350, 27 pages, 2009. https://bit.ly/3QpFbhT

32. Shih, *op. cit.*, p. 223.

33. ISO/DIS 7730: "Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria," https://bit.ly/45NeVT0

34. ISO 7933:2004(en) "Ergonomics of the thermal environment — Analytical determination and interpretation of heat stress using calculation of the predicted heat strain," https://bit.ly/3tKpWaq

35. Shih, *op. cit.*, p. 223.

36. Reference Air Mass 1.5 Spectra, ASTM G-173. https://bit.ly/3QrA7tu

37. Adapted from Fig. 3-28 in Modest, M.F. Radiative Heat Transfer, 3rd ed., Addison-Wesley (2013), p. 97.

38. Schroeder, D. V. (2000). An introduction to thermal physics. Addison-Wesley. pp. 305–7. ISBN 978-0-321-27779-4

39. Oort, A.H.; Peixoto, J.P. (1992). Physics of climate. New York: American Institute of Physics. ISBN 978-0-88318-711-1

40. Greenhouse effect, Wikipedia; https://bit.ly/3s2M3Zk

**Paul T. Arveson**'s main career was as a physicist in the Navy, where he served as a researcher leading projects in acoustics and oceanography. He has a BS in Physics and an MS in Computer Systems Management. He is a Fellow of the Washington Academy of Sciences.

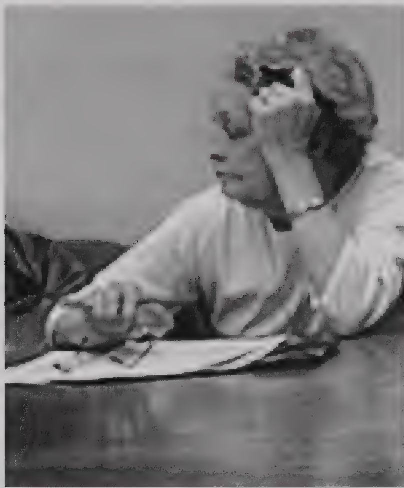
# Vary T. Coates
## 1930 – 2023

Sethanne Howard
USNO/retired

**Vary Coates** was a long-time Life Fellow and supporter of the Washington Academy of Sciences. Until she had trouble walking she attended and participated in Academy Board meetings. She and Peg Kay (another Academy icon) were good friends. She served as editor of the Journal of the Washington Academy of Sciences for many years. Under her leadership the Journal maintained a high standard for scientific integrity. She also created the current template in use for printing the Journal.

It was Vary who convinced the man who taught Koko sign language to write up his work (which he had never done) and publish it in the Journal. She always knew someone in the DC area who would write a scientific paper for the Journal. I learned about editing a scientific journal from her and became editor after she retired. She was a superb mentor, and we became close friends. She and Joe lived on Connecticut Ave in Washington DC for many years. I visited their home several times always amazed at the things they had collected over the years. Eventually they moved, still on Connecticut Ave, into an assisted living facility where I continued to visit them. After Joe died I continued to visit Vary. I kept the Academy apprised of her status. We all knew that she loved chocolate of any kind. So when she had surgery several of us visited her in the hospital and brought, yes, chocolate, lots of chocolate. She ultimately had a scooter she would drive with great flair. We would go out to the sidewalk on Connecticut to go to a nearby Greek restaurant for lunch. I could not keep up with her scooter on the sidewalk. She always got there first. I cherished her friendship.

Vary T. Coates died peacefully on May 11 at the home of her son, Peter Coates, and his wife, Susan Jennings, in New Jersey. She was 92. Vary's parents, brother, husband, and eldest daughter, Marcy Canavan, preceded her in death. I will miss her dearly. As you will learn from her bio, she traveled widely and engaged in a diverse type of activities. The bio is provided by her daughter Anna Scotti.



This photo is of Vary at a meeting of
the Board of Managers of the Academy in 2008.

Born Vary Ellen Taylor in 1930 in Anderson, South Carolina, Vary met Joseph F. Coates of Brooklyn, New York, in 1951, and they married the following year. Although they lived briefly in Philadelphia and in New Jersey, for most of their long lives together Vary and Joe lived in Washington, D.C., where they raised their family.

Vary was graduated from Furman University in 1951. In a time when few women pursued advanced degrees, she earned an M.A. in Public Affairs (1967) and a Ph.D. in Political Science (1972) from George Washington University. She also studied at Pennsylvania State College and was an intern in the U.S. Foreign Service Institute. In addition to her earned degrees Vary was awarded an Honorary D.Sc. from Webster College, Missouri, in 1983.

After completing her degrees Vary stayed on at GWU as Associate Director of the Program of Policy Studies in Science and Technology and as the Head of the Technology Assessment Group. During the late 1970s and early 1980s she was Director of Policy Studies at Dames and Moore. Sometime after the founding of J. F. Coates Inc. in 1979, she joined Joe in the company as Vice-President and Project Director. She was a senior associate in the Office of Technology Assessment, U.S. Congress, from 1983 until OTA was closed in 1995. Subsequently she served as president of

the Institute for Technology Assessment and also a consultant to the U.S. Nuclear Regulatory Commission.

Throughout her career, Vary published extensively in the field of technology assessment, both separately and together with her husband. During her employment at OTA, she directed several assessment projects, including Automation of American Offices (1985), Electronic Bulls and Bears: U.S. Securities Markets and Information Technology (1990), and U.S. Telecommunications Services in European Markets (1993). Vary also enjoyed a lively career as a professor, teacher, and journal editor. She taught in the graduate program at American University and at George Washington University, was active in the World Future Society, and served as editor of the Journal of the Washington Academy of Sciences and as a member of the Academy's Board of Managers. Vary's papers, along with Joe's, are archived at the Georgia Institute of Technology.

Vary's very long and happy life was occasionally punctuated by tragedy. She lost both her brother and her daughter Marcy to untimely death. Her beloved husband, Joe, died in 2014. Vary faced life with such courage and enthusiasm that her children were unaware, until their adulthoods, that she had a moderate physical disability. She loved to travel, and visited well over a hundred countries over the course of her life. She especially enjoyed trips to Japan, The Netherlands, Poland, and England, and to California and New Mexico to visit her far-flung children. She also loved literature, poetry, crossword puzzles, chocolate, pinot grigio, Forensic Files, dogs, and cats.

Vary's matriarchal empire is vast. She is survived by four of her children; Peter Coates (Susan Jennings), Matthew Coates (Berta Najera), Anna Scotti, and Elizabeth Coates (Damian Kessler); by her son-in-law, Richard Canavan; by ten grandchildren; Kelly Canavan, Sean Canavan, Emily Canavan, Ryan Thomas, Dodge Coates, Arliss Coates, Maureen Kessler, William Kessler, Katherine Kessler, and Victoria Scotti; by two great-grandchildren, Milo Bruner and Jackson Thomas; by several step-grandchildren, including Chase Jennings, Ellis Jennings, and Merida Lang; and by many beloved nieces and nephews, including Katherine Taylor, Andrew Taylor, Emily Taylor, Bella Najara, Amanda Caruso, Daniel Caruso, and their children. Vary is also survived by her former sister-in-law, Brenda Taylor (Richard Perreault) and by her husband's nieces and nephews, including Bill and Pat Coates. In the final years of her life Vary was lov-

ingly cared for by three women, Olimpia Cruz Guridas, Odalis Duran, and Jacqueline Sanchez, to whom her family are very grateful.

A life-long feminist and Democrat, Vary cared deeply about social justice. She supported progressive causes throughout her life. She especially admired the work of Planned Parenthood (https://bit.ly/3FrN1kZ) and the ACLU (https://bit.ly/3SdmUFP), and the family welcomes contributions to those organizations in lieu of flowers. No service is planned at this time. With characteristic generosity, Vary directed that her remains be used for scientific research. Her ashes will be returned to the family within three years, and a memorial service may be scheduled at that time.

Vary will be deeply missed by her children and all who knew her. Contact her family at varycoatesobituary@gmail.com.

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